PATENT SPECIFICATION

(11) 1 242 509

DRAWINGS ATTACHED

1 242 509

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B5A 2A4A 9

(54) THERMOFORMING OF THERMOPLASTIC POLYMERS

(71) I, CONRAD GOLDMAN, a citizen of the United States of America, of 298, Hazelwood Terrace, Rochester, New York 14609, United States of America, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates in general to the thermoforming of plastic materials, and more particularly to methods of thermoforming plastic materials utilising electromagnetic field energy to heat polar thermoplastics, or thermoplastics containing polar groups, that is polar materials of high Dissipation Factor. Heating by electromagnetic field energy as applied to thermoplastic materials is generally referred to as dielectric heating of which radio frequency heating, abbreviated to RF heating, is the form most commonly used. The present invention is related to that of Application No. 3897/68, Serial No. 1238881.

RF energy and microwave energy and other forms of electromagnetic energy have been used to heat rubber, preheat thermoplastic materials and thermosetting materials and to dry lumber. The heating effect is contingent on the material having a high Dielectric Loss Factor, which in general terms is the same as the Dissipation Factor.

In thermoforming of plastic materials, infrared units have been employed to soften the materials, before forming is accomplished. Use of hot air ovens, heating on two sides by means of heated platens, and other modifications of heating techniques have been employed to obtain reasonable heating rates, and uniform heating. Since plastics in general are materials of relatively low thermal conductivity, objects are restricted to rather thin gauges, for economic reasons, to obtain reasonable heating and cooling cycles.

Where thick sections are to be thermoformed, RF heating can heat the material rapidly and uniformly, if it has sufficient polarity to respond to electromagnetic field energy. With thin gauge material, RF heating is less favourable, since much thermal energy is lost by radiation, conduction, and convection.

There is a gap in thermoforming technology. Some articles and components might best be made by rapidly heating thick sections of plastic material and then forming; however, thick sections do not generally heat thoroughly in a short time with infrared heating, or by hot air systems.

It is a primary object of this invention to provide improved methods of heating thin as well as thick gauge polar plastic materials by RF heating. Additional objects of the invention will be evident from the following description.

According to one aspect of the invention a process for RF heating thermoplastic sheeting in thicknesses greater than .050 inches, having a Dissipation Factor greater than .0030, comprises placing unheated sheets of thermoplastic and carrier release agent at one end of a stack of pairs of thermoplastic sheet and carrier-release agent, and removing a heated sheet and carrier-release agent from the other end of the stack of pairs of thermoplastic sheet and carrier-release agent, during each cycle of operation, each cycle to include heating of the entire stack by RF heating.

It is further shown that the invention is applicable to a process in which a continuous flexible thermoplastic sheet can be treated in similar manner whether by continuous movement or intermittently.

Considering the operation of RF Heating equipment, as used with materials having a high Dissipation Factor:— The energy absorbed by the material being heated depends upon its specific heat, its mass, and the temperature range through which the material is heated. In terms of symbols; $Q = mc\,\Delta t$, where Q represents the energy; m the mass; c the specific heat and Δt is the temperature differential through which the material is heated. This can be related to the electrical energy consumed by the Radio Frequency Heating

equipment. Knowledge of the plate current and the plate voltage, considered at 'no-load' and at operating conditions, enables the power requirements for dielectric material being heated, to be calculated, when the time of heating is noted. Neglecting thermal losses due to radiation and conduction of the material being heated, the relationship between the Btu's absorbed thermally, and the power consumed electronically is:

$$\frac{mc\,\Delta t}{HR} \propto \text{plate voltage} \times (\text{load---no load}) \text{ current}$$

Using the convertibility factor that 3415 $\frac{BTU}{HR}$ = 1 kw. the amount of electronic energy, in the form of RF energy required to process a predetermined weight of plastic per hour, can be calculated.

The question of how much heat can be absorbed *per unit time* per pound of material will influence the size of the RF Unit required to heat a specific amount of material per hour. Certain materials having a relative low Dissipation Factor can only absorb energy at relatively slow rates, and the RF energy ratings of the RF Heating units can be quite low; using larger equipment only results in the equipment operating at a fraction of its rated capacity. For optimum operating conditions, equipment should be run close to its rated capacity, since the 'no-load' consumption can be a substantial fraction of the 'operating load' where equipment is run substantially below its rated capacity.

With materials having a low Dissipation Factor, the time factor must be increased to enable sufficient energy to be absorbed per unit weight of material being heated. This is usually accomplished by increasing the dwell time, in a fixed plate RF heating unit or employing multiple units in series. The present disclosure indicates methods for increasing heating time for material being heated continuously, or in semi-continuous sequences, for both thin gauge and heavy material.

The invention will be further understood by considering the accompanying drawings. In these drawings:—

Fig. 1 is a schematic diagram indicating the flow pattern of heavy gauge sheets in a fixed plate RF heater;

Fig. 2 is a schematic diagram indicating the flow pattern of thin gauge film in a Fixed Plate RF Heater;

Fig. 2A shows the heater of Fig. 2 in a closed position;

Fig. 3 indicates graphically the relationship between the energy absorbed by a plastic material being heated by RF energy, and the Dissipation Factor of the plastic material, under the conditions of RF heating.

Fig. 4 indicates graphically the relationship between the rate of heating of a plastic material being heated by RF energy, and the Dissipation Factor of the plastic material under the conditions of RF heating.

Fig. 5 indicates graphically the variations in power consumption with time, during heating, as well as temperature variations with time during RF heating.

Referring to Fig. 1, and considering in greater detail, the heating of heavy gauge sheets of .060 to .500 inches and heavier, by RF heating;— A thermoplastic sheet 1 to be thermoformed, of a sufficiently high Dissipation Factor to respond to RF heating, is placed on a sheet 2 of release agent or carrier sheet, employed in RF heating units. The carrier sheet may be silicone rubber or polytetrafluoroethylene, which possess the desirable properties of being a release agent, which will be unaffected by the temperatures normally encountered in heating of sheets for thermoforming operations. Any other material having these properties may be similarly employed. The stack of sheets of release agent and thermoplastic sheets to be RF heated for thermoforming is lifted by suitable means, between the RF electrodes, 3 and 4, and an unheated sheet of thermoplastic and its carrier is placed on the bottom electrode. The top sheet 5 and its carrier 6 is removed from the stack by suitable means, and the carrier is separated from the heated sheet, for reuse with unheated sheets, while the heated sheet is fed into a thermoforming unit, where it is formed into articles of commerce. The remainder of the stack is replaced on top of the unheated sheet and carrier, the top electrode is brought into operating position, if necessary, and RF energy is applied. At timed intervals, corresponding to the thermoforming cycle employed for the sheets being RF heated and thermoformed, the cycle of introducing a sheet and carrier, removing a sheet and carrier, and heating the stack, is repeated. Needless to say, the unheated sheet and carrier may be introduced at the top of the stack, and the heated sheets removed from the bottom of the stack, during each cycle; however, since the unheated sheets are more rigid, it is preferred to introduce the unheated sheets at the bottom, for greater ease of handling of the stack, as well as handling of the individual sets of sheet and carrier. The number of sets of sheet and carrier handled in a stack will depend on the temperature to

which the sheets must be heated for thermoforming, which is related to the type of plastic being heated, the time cycle of the thermoforming unit, the Dissipation Factor of the sheets, the Power Rating of the RF unit, and other pertinent factors.

Where it is desired to avoid using release agents or carriers in the above process for heating sheets electronically, the stack may be heated to a temperature sufficiently below the fusion point to avoid blocking or fusion of one sheet to the next, in one heating unit, followed by heating of the hottest individual sheet, to thermoforming temperatures in a second RF heating unit. This will eliminate the need for handling and utilising carriers. Most thermoplastic materials have a higher Dissipation Factor at elevated temperatures, therefore the heating time for the preheated individual sheets can be relatively short compared to the initial heating cycle, while passing through the stack in the primary heating unit. By controlling the number of sheets in the primary stack, the time to heat the sheet in stacked form can be coordinated with the time to further heat the sheet individually in the secondary heating unit, to prepare the sheet for thermoforming. Under optimum conditions, the thermoforming cycle will equal each heating cycle so that a semi-continuous operation can be established, with maximum production rates.

Considering the heating of thin gauge sheeting and film which can be wound around rolls of small diameter, and referring to Fig. 2:— In order to increase the time of exposure of the thin sheeting to RF energy, the web 7 is caused to pass back and forth in forward and reverse direction between the RF electrodes 8 and 9. The rolls, such as 10, over which the sheeting and its carrier films are passing may be idler rolls or driven rolls, and should be constructed of such material as to not affect the RF field, or absorb energy from the RF field.

With sufficiently high powered RF units, where the sheeting is passing between the electrodes at rapid speeds, continuously, air gaps between the layers of sheeting (including the top and bottom transporting film) can be tolerated. Where maximum heating rates are required with RF units of optimum rating for the application involved and where intermittent progress of sheeting through the RF heating unit can be accommodated by the processing line, the two plates of the Fixed Plate RF unit can be intermittently brought closer together, as shown in Fig. 2A, and further apart as shown in Fig. 2. When the two plates are in the open position (further apart), the sheeting can be advanced a specific length, equal to the amount being thermoformed per cycle. The plates are then brought into closer proximity, compressing the sheets into a denser mass, thereby enabling the concentration of polar mass per unit volume between the plates, to be increased to a practical maximum, which will allow the RF unit to convert the maximum amount of energy into heat within the thermoplastic material being heated. The time cycle for advancing a specified length, and heating the multiple layers of thermoplastic sheeting should be adapted to the time cycle of the thermoforming unit operating in conjunction with the RF heating unit.

As with the heavy gauge cut sheet operation described above, the total area of sheeting exposed to RF heating and the rate at which it passed through the heating unit will depend on several factors, including the temperature to which the sheeting must be raised, the Dissipation Factor of the sheeting, the Power Rating of the RF unit and other pertinent considerations related to the processing equipment and their time cycles.

WHAT I CLAIM IS:—

1. A process for Dielectrically cyclically heating thermoplastic sheeting in thicknesses greater than .050 inches, having a Dissipation Factor greater than .0030, which comprises placing unheated sheets of thermoplastic and carrier-release agent at one end of a stack of pairs of thermoplastic sheet and carrier-release agent sheet, and removing a heated sheet and carrier-release agent sheet from the other end of the stack of pairs of thermoplastic sheet and carrier-release agent sheet, during each cycle of operation, each cycle including cyclically heating the entire stack by Radio Frequency heating.

2. A process for Dielectrically heating initially rigid thermoplastic sheeting which comprises placing unheated sheets of thermoplastic at one end of a stack of thermoplastic sheets in a primary cyclically operating Dielectric heating unit, and in each heating cycle removing a heated sheet from the other end of the stack, the maximum temperature of any sheet in the stack being controlled to be sufficiently below the fusion point to avoid blocking or fusion of one sheet to the next, followed by further heating of the hottest sheet from the stack in the primary Dielectric heating unit to thermoforming temperatures in a second Dielectric heating unit.

3. A process for Dielectrically heating a single continuous flexible thermoplastic sheet of Dielectrically responsive material which comprises simultaneously passing a multiplicity of layers thereof in alternating directions between the electrodes of a Radio Frequency heating unit.

4. A process for Dielectrically heating a single continuous flexible thermoplastic sheet of Dielectrically responsive material, which comprises passing a stack of layers of Dielectrically responsive thermoplastic sheeting and carrier-release agent sheeting between the elec-

trodes of a Radio Frequency heating unit in intermittent manner and in alternating directions, which comprises entering a specified length of sheeting into the unit while the electrodes are sufficiently separated to permit motion of the sheeting between the electrodes, followed by compaction of the stack of stationary layers between the electrodes by reduction in spacing between the electrodes, heating of the compacted stack, separation of the electrodes, and subsequent advancement of the sheeting by the specified length in specified time intervals.

5. A process according to any previous Claim including the preliminary preparation of the sheeting in the manner described in co-pending Application No. 3897/68, Serial No. 1238881.

6. A process according to any previous Claim performed substantially as herein described with the aid of the accompanying drawings.

7. Apparatus adapted to perform the process of any previous claim constructed and operable substantially as described with reference to any example illustrated by the accompanying drawings.

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1242509 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

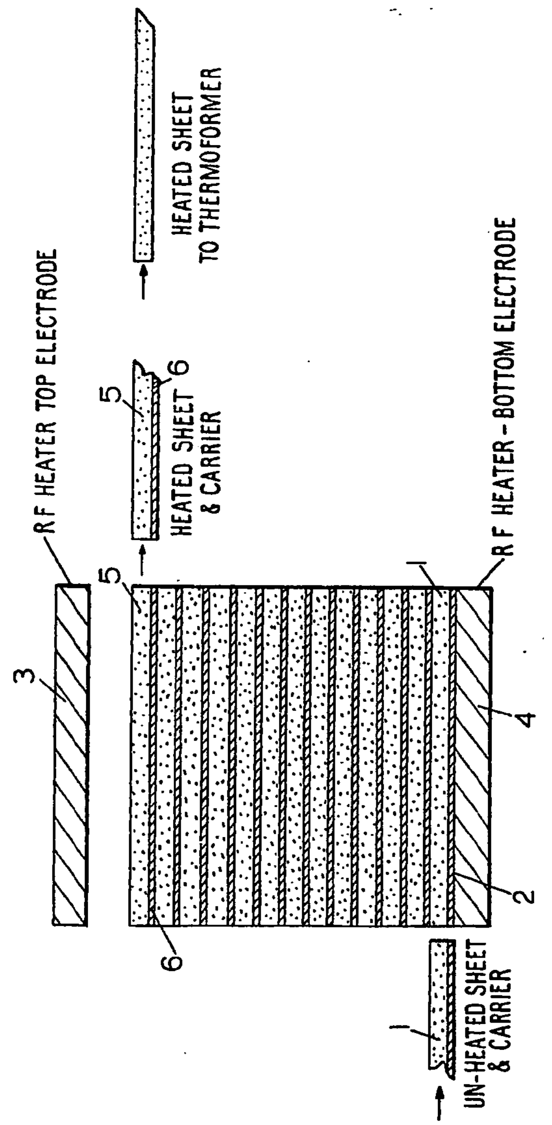


FIG. 1.

1242509 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

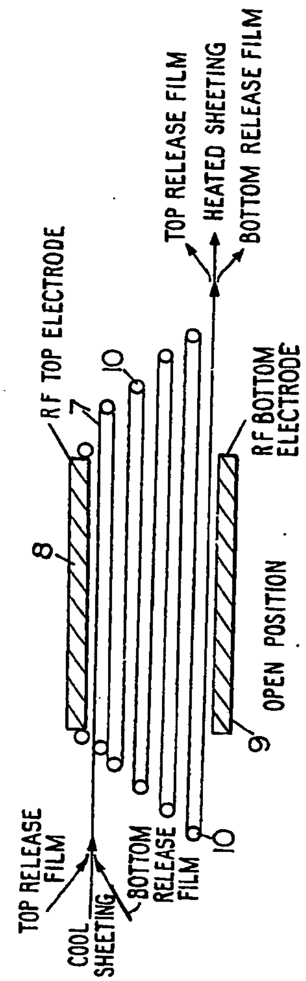


FIG.2.

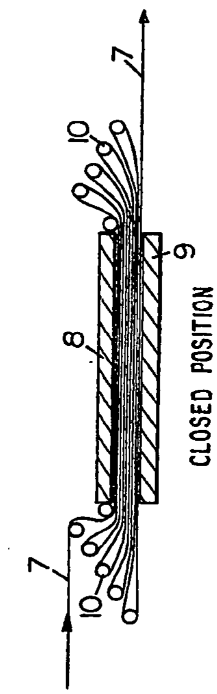
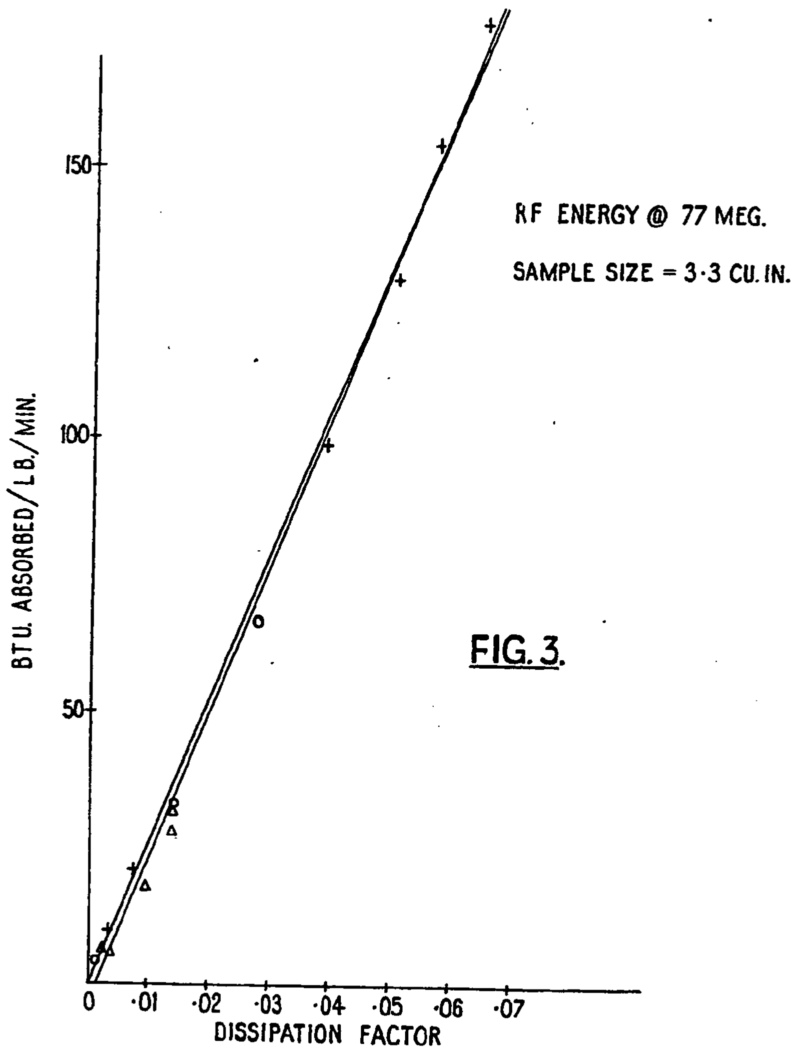


FIG.2A.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BTU. ABSORBED/LB./MIN.
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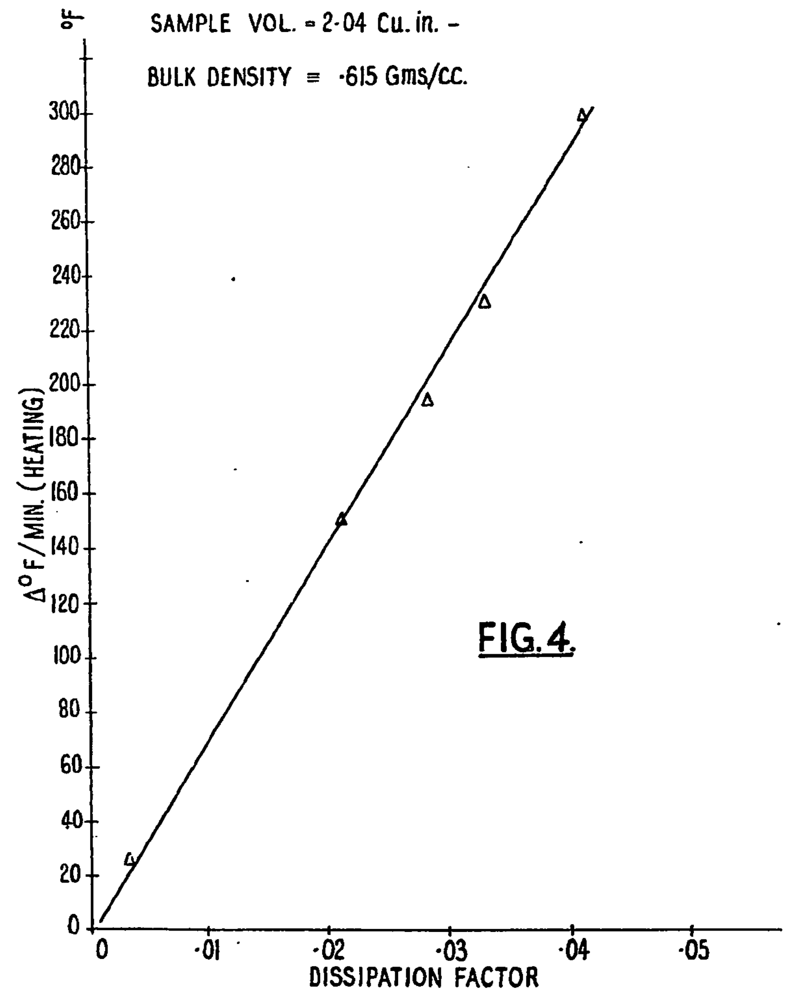
50
0
·01
·02
·03
·04
·05
·06
·07
DISSIPATION FACTOR

FIG. 3.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20
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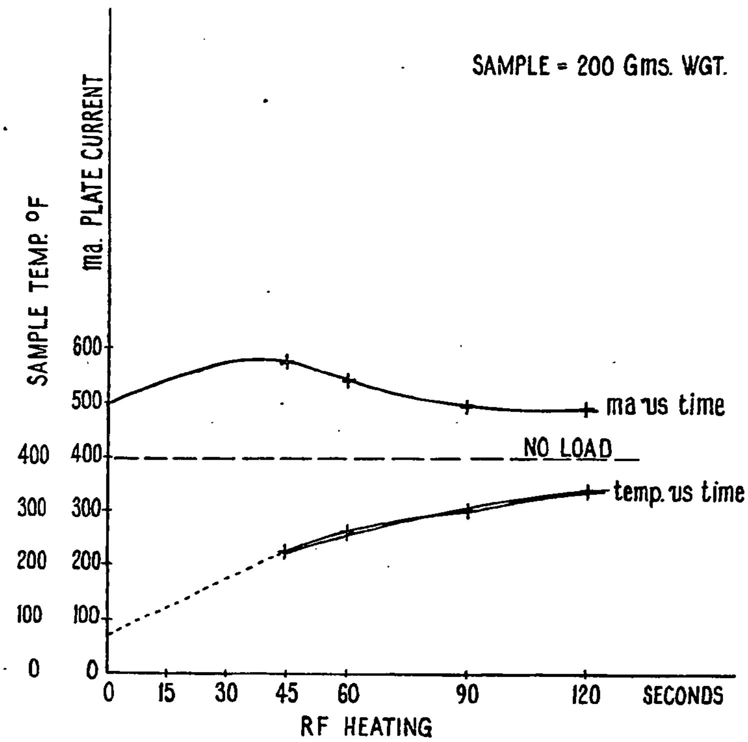
60
80
100
120
140
160
180
200
220
240
260
280
300
0
·01
·02
·03
·04
·05
DISSIPATION FACTOR

FIG. 4.

FIG. 5.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500
400
300
200
100
0
ma vs time
NO LOAD
temp. vs time
0
15
30
45
60
90
120
SECONDS
RF HEATING